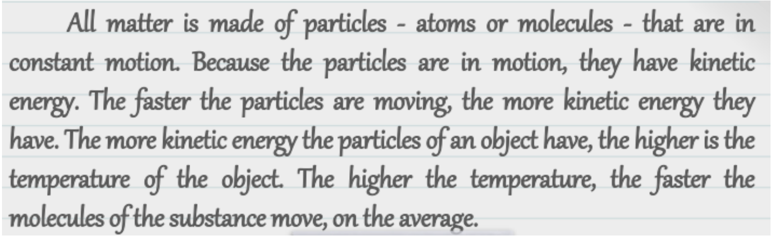
I. TEMPERATURE MEASUREMENT

TEMPERATURE (sometimes called **thermodynamic temperature**) - is a measure of how hot or cold something is: specifically, a measure of the average **kinetic energy** of the particles in a system. While there is no maximum theoretically reachable temperature, there is a minimum temperature, known as **absolute zero**, at which all molecular motion stops



All matter is made of particles - atoms or molecules - that are in constant motion. Because the particles are in motion, they have kinetic energy. The faster the particles are moving, the more kinetic energy they have. The more kinetic energy the particles of an object have, the higher is the temperature of the object. The higher the temperature, the faster the molecules of the substance move, on the average.

ANSI - American National Standard Institute

HISTORY ABOUT TEMPERATURE

1592 - Galileo Galilei invented the liquid -in -glass thermometer.

1643 - Athanasius Kircher invented the first mercury thermometer.

1714 - Daniel Gabriel Fahrenheit invented both the mercury and the alcohol thermometer with Fahrenheit scale.

1742 - Anders Celsius proposed centigrade scale

1800's - William Thomson (later Lord Kelvin) postulated the existence of an absolute zero.

1821 - Sir Humphry Davy noted the temperature dependence of metals.

1932 - C.H. Meyers built the first Resistance Temperature Detector (RTD). 20th century - The development of temperature sensors fully developed.

20th century - the development of temperature sensors fully developed

TEMPERATURE UNITS

- Celsius
- Kelvin
- Fahrenheit

CONVERSIONS BETWEEN TEMPERATURE UNITS

- °C = 5/9 °(F - 32)
- °F = 9/5 (°C) + 32
- K = 273 + °C

TEMPERATURE MEASUREMENT - known as **thermometry**, describes the process of measuring a current local temperature for immediate or later evaluation.

CLASSIFICATIONS OF TEMPERATURE MEASURING INSTRUMENT

1. **Thermometers** (Non-electric Temperature Sensors)
2. **Probes** (Electronic Thermometers/Sensors)
3. **Non-contact** (Non-contact Temperature Sensor)

PRINCIPLE OF OPERATION OF EACH TEMPERATURE MEASURING INSTRUMENTS

NON-ELECTRIC TEMPERATURE SENSORS

1. Liquid-in-Glass Thermometers
2. Bimetallic Thermometers
3. Filled-bulb Systems

Liquid-In-Glass Thermometers

used mercury as the liquid. The element **mercury** is liquid in the temperature range of about −40 to 700 °F (−38.9 to 356.7 °C). **Because of mercury's toxicity and the strict governing laws, the use of the mercury-in-glass thermometer has declined**

Bimetallic Thermometers

bonding two dissimilar metals with different coefficients of expansion produces a bimetallic element.

Thermostats have a range of 100 to 1000 °F (−73 to 537 °C).

Solids tend to expand when heated. The amount that a solid sample will expand with increased temperature depends on the **size of the sample, the material it is made of, and the amount of temperature rise.**

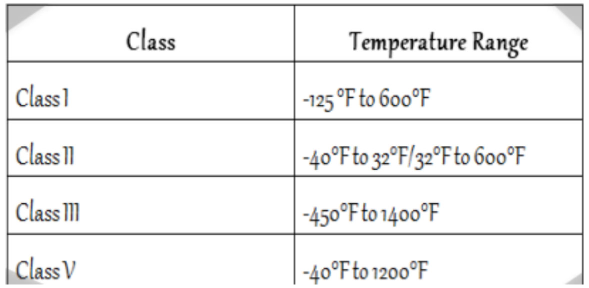
If we bond these two strips of metal together, this differential growth will result in a bending motion that greatly exceeds the linear expansion.

Filled-Bulb Systems

used for decades. They have a useful range of - 125 °F to 1200 °F.

Filled-bulb systems exploit the principle of fluid expansion to measure temperature. If fluid is enclosed in a sealed system and then heated, the molecules in that fluid will exert a greater pressure on the walls of the enclosing vessel. **By measuring this pressure, and/or by allowing the fluid to expand under constant pressure, we may infer the temperature of the fluid.**

Four Types of Filled Bulb Temperature Sensors in use in industrial applications:



Class	Temperature Range
Class I	-125 °F to 600°F
Class II	-40°F to 32°F/32°F to 600°F
Class III	-450°F to 1400°F
Class V	-40°F to 1200°F

1. **LIQUID FILLED SYSTEMS TEMPERATURE SENSORS (CLASS I)**

   Class I systems use a liquid fill fluid. Here, the volumetric expansion of the liquid drives an indicating mechanism to show temperature as shown. The steel bulb, stem and indicator are completely filled under pressure with a liquid. The system is totally filled to provide a constant volume. **Expansion of the fluid in the tube is converted to pressure.** This pressure expands the Bourdon tube which moves the pointer on the scale. The filling fluid is usually an inert hydrocarbon, such as **xylene**

2. **VAPOR FILLED SYSTEMS TEMPERATURE SENSORS (CLASS II)**
   The vapor filled system uses a volatile liquid/vapor combination to generate a temperature dependent fluid expansion. This form of measurement is based on the vapor-pressure curves of the fluid and measurement occurs at the transition between the liquid and vapor phases.

3. **GAS FILLED SYSTEMS TEMPERATURE SENSORS (CLASS III)**
   The change in pressure with the temperature allows us to sense the bulb's temperature.As the volume is kept constant, the pressure varies in direct proportion to the absolute temperature.

- provide a faster response than other filled devices
- useful in pneumatic systems
- **Nitrogen** is quite commonly used with gas filled systems.

4. **MERCURY FILLED SYSTEMS TEMPERATURE SENSORS (CLASS V)**
   Mercury expansion systems are different from other liquid filled systems because of the properties of the metal. **Mercury is toxic and can affect some industrial processes and is used less in a filled system.** Mercury filled system provides the widest range of operation (-40 °C to 650°C

ELECTRONIC THERMOMETERS/SENSORS

1. Thermocouples
2. Resistance Temperature Detectors (RTD)
3. Thermistors

THERMOCOUPLES - an assembly of two wires of unlike metals joined at one end designated the hot end.

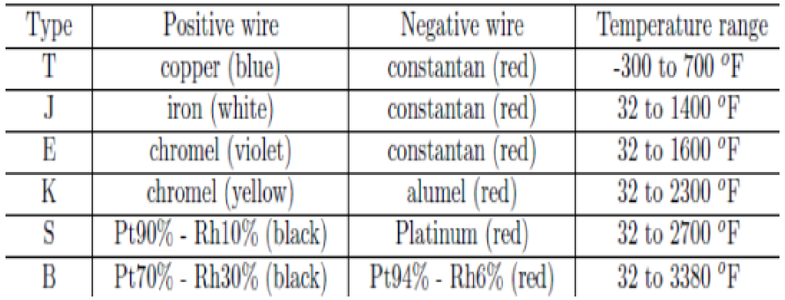
- **Seebeck voltage**, this voltage (electromotive force) depends on the difference in temperature between the hot and the cold junction and the Seebeckcoefficient of the two metals.

PRINCIPLE OF OPERATION OF THERMOCOUPLES

1. **Peltier Effect** - If the junctions of a thermocouple are at the same temperature and a current is passed through the circuit of the thermocouple, heat is produced at one junction and absorbed at the other.
2. **Thompson Effect**- The absorption or evolution of heat when current is passed through an unequally heated conductor.
3. **Seebeck Effect** - When two dissimilar metals with different temperatures and they're touching, they produce an emf or voltage

When two dissimilar metal wires are joined together at one end, **a voltage is produced at the other end that is approximately proportional to temperature.** That is to say, the junction of two different metals behaves like a temperature sensitive battery.

THERMOCOUPLE TYPES



Type	Positive wire	Negative wire	Temperature range
T	copper (blue)	constantan (red)	-300 to 700 °F
J	iron (white)	constantan (red)	32 to 1400 °F
E	chromel (violet)	constantan (red)	32 to 1600 °F
K	chromel (yellow)	alumel (red)	32 to 2300 °F
S	Pt90% - Rh10% (black)	Platinum (red)	32 to 2700 °F
B	Pt70% - Rh30% (black)	Pt94% - Rh6% (red)	32 to 3380 °F

RESISTANCE TEMPERATURE DETECTORS (RTD) - is a temperature sensor which measures temperature using the principle that the **resistance of a metal changes with temperature.**

- For most metals the change in electrical resistance is directly proportional to its change in temperature and is linear over a range of temperatures. This constant factor called the **temperature coefficient of electrical resistance** is the basis of RTDs.
- work on a basic correlation between metals and temperature
- measured in ohms (Ω)
- most common RTD specification is 100 Ω, which means that at0 ° C the RTD element should demonstrate 100 Ω of resistance

TWO TYPES OF RTD

1. **Thin Film Type -** are made by depositing a thin layer of resistive material, typically platinum film, onto a ceramic substrate. A pattern is then etched onto the element, creating the electrical circuit.
2. **Wire Wound Type -** are built using a small diameter wire, typically platinum, which is wound into a coil and packaged inside a ceramic insulator. Larger extension wires are then spot welded to the platinum wire.

THERMISTORS - a resistive device that changes its resistance predictably with temperature.

Difference between RTDs and Thermistors

- Thermistors are devices made of **metal oxide** which either increase in resistance with increasing temperature (a positive temperature coefficient) or decrease in resistance with increasing temperature (a negative temperature coefficient). RTDs are devices made of **pure metal** (usually platinum or copper) which always increase in resistance with increasing temperature.
- The major difference between thermistors and RTDs is **linearity**: thermistors are highly sensitive and nonlinear, whereas RTDs are relatively insensitive but very linear.

NON-CONTACT TEMPERATURE SENSORS

1. Pyrometers
2. Radiation Pyrometers

PYROMETERS - called as **Radiation Thermometers** was invented by Josiah Wedgwood.

used to measure the temperature which is difficult to measure

- used to measure temperature above 1500 degree Celsius, contact devices may melt at this temperature.

2 TYPES OF PYROMETERS

1. **Optical Pyrometer -** uses this radiation to measure the temperature of the object. The brightness of the measured object is compared with the brightness of the lamp at a reference temperature
2. **Infrared / Radiation Pyrometer -** the radiation pyrometer has an optical system such as it has an optical lens, mirror, and adjustable eyepiece. The heat energy is transferred through the optical lens to the mirror. The mirror focuses this energy on the detector.

RADIATION PYROMETERS - also referred to as infrared (IR) thermometer is a noncontact radiant energy detector.

- measure the intensity of the radiant energy and produce a signal proportional to the target temperature
- The physics behind this broadcasting of energy is called **Planck's Law of Thermal Radiation.**

APPLICATIONS OF THE FIELDS OF TEMPERATURE MEASUREMENT

1. Motors
2. Home appliances
3. Computers
4. Industrial equipment
5. Food Production; 3D printed chocolates
6. Exhaust Gas Monitoring on Motorsport Vehicles

THERMOCOUPLE LAWS

1. Law of Homogeneous Materials
2. Law of Intermediate Materials
3. Law of Successive or Intermediate Temperatures

Law Of Homogeneous Materials

This law states that a thermocouple circuit made with a homogeneous wire cannot generate an emf, even if it is at different temperature and thicknesses throughout.

If two thermocouple junctions are at T1 and T2. then the thermal emf generated is independent and unaffected by any temperature distribution along the wires.

Law Of Intermediate Materials

This law is interpreted to mean that the addition of different metals to a circuit will not affect the voltage the circuit creates. The added junctions are to be at the same temperature as the junctions in the circuit.

Law Of Successive Or Intermediate Temperatures

This law allows a thermocouple that is calibrated with a reference temperature to be used with another reference temperature. It also allows extra wires with the same thermoelectric characteristics to be added to the circuit without affecting its total emf.

MERCURY THERMOMETER

- Is a type of thermometer consisting of mercury contained in a bulb at the bottom of a graduated sealed glass capillary tube marked in degrees Celsius or fahrenheit; mercury expands with a rise in temperature causing a thin thread of mercury to rise in the tube.

CHANGE-OF-STATE TEMPERATURE SENSOR

- Change-of-state temperature sensors consist of labels, pellets, crayons, lacquers, or liquid crystals whose appearance changes once a certain temperature is reached.

WALL THERMOMETER

A thermometer device used for measuring and displaying the temperature of a room or an area

THERMAL IMAGING SCANNER

It can measure and capture thermal images of an object or anything you prefer. Each item emits electromagnetic radiation as heat. Thus, a thermal imaging camera measures the temperature that the object emits and then, through a complex transformation, create a thermal image of the item

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II. PRESSURE MEASUREMENT

INDUSTRIAL PRESSURE MEASUREMENT - The Measurement and Control of Pressure is very important in almost all chemical and Petrochemical Industries, Power Plants, and other Industries. Many of the processes in these industries used liquids, gasses, steam, etc. which required highly accurate measurement and control of pressure for trouble free and safety operation.

➢ **PRESSURE** - one of the key thermodynamic parameters

- Is an intensive property
- defined as a ratio between a force and a unit area, perpendicular to the direction of that force, on which the force acts. Mathematically this definition is expressed as: $p = \frac{F}{A}$
- as the amount of force being applied to an area

➢ **PRESSURE OF A FLUID (P)** - fluid molecules will be in constant and random motion called "**Brownian motion**", due to which fluid at rest in a vessel, does exert force on all the walls of the vessel, with which it is in contact.

TOTAL PRESSURE OF A FLUID IN A NOMINATED POINT CONSISTS OF TWO ELEMENTS:

1. **Static Pressure** - Also referred as “**hydrostatic pressure**” is the pressure of a fluid at rest.
    - a pressure not associated with the fluid motion, but its state. It is the pressure which would be indicated by a gauge moving together with the fluid
2. **Dynamic Pressure** – the pressure of a fluid moving.
    - A measurement of kinetic energy of a moving fluid and depends on its velocity and density.

FLUID - Any substance that does not conform to a fixed shape such as liquid or gas.

HISTORY

GALILEO GALILEI (1564-1642)

- The Italian Galileo Galilei was granted the patent for a water pump system used on irrigation.
- Found that 10 meters was the limit to which the water would rise in the suction pump, but had no explanation for this phenomenon. Scientists were then devoted to finding the cause for this.

EVANGELISTA TORRICELLI (1608-1647)

- In 1643, the Italian physicist *invented the barometer,* with which he could evaluate the atmospheric pressure. His research about mercury columns paved the way to his discovery of vacuum.

BLAISE PASCAL (1646)

- a French physicist used the barometer to show that the air pressure was smaller at the top of the mountains. He also determined the weight of air and called it “pressure”.

EUGÈNE BOURDON

- In 1849, Eugène Bourdon was granted the Bourdon Tube patent, used until today in relative pressure measurements

THE FOUR COMMON REASON WHY WE MEASURE PRESSURE

1. Safety – prevent pressurized pipes and vessels from bursting
2. Process Efficiency – variation of pressure below or above a set-point will result in scrap rather than usable product in some manufacturing process
3. Cost Saving
4. Inferred Measurement Of Other Variable

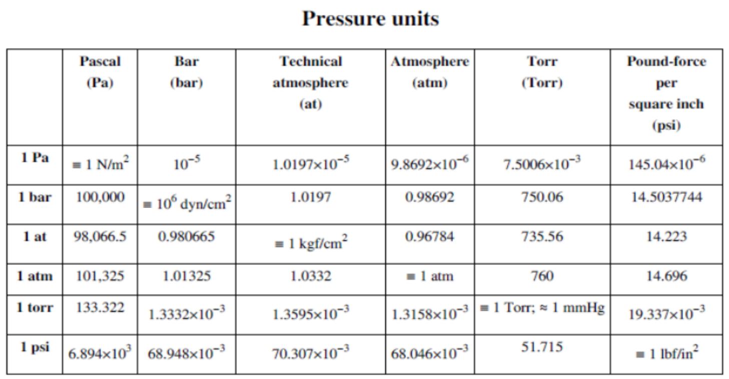
MOST COMMON TYPES OF PRESSURE MEASUREMENT

1. **Absolute Pressure** - it is measured with relation to the perfect vacuum, namely, the pressure difference at a given measurement point by the vacuum pressure (absolute zero). Normally the ABS notation is used when this greatness is indicated.

2. **Differential Pressure -** it is the pressure difference measured between two points. When any point other than vacuum or atmosphere is used as reference it means differential pressure.

3. **Gauge Pressure** - it is measured in relation to the ambient pressure, namely, in relation to the atmosphere. It is always important to register on the notation that it is a relative measurement.
4. **Atmospheric Pressure or Barometric Pressure** - is the pressure within the atmosphere of Earth

UNITS OF PRESSURE - pressure is normally measured in unit of force per unit of surface area



Pressure units

	Pascal (Pa)	Bar (bar)	Technical atmosphere (at)	Atmosphere (atm)	Torr (Torr)	Pound-force per square inch (psi)
1 Pa	$\equiv 1\ \mathrm{N/m^2}$	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	100,000	$\equiv 10^6\ \mathrm{dyn/cm^2}$	1.0197	0.98692	750.06	14.5037744
1 at	98,066.5	0.980665	$\equiv 1\ \mathrm{kgf/cm^2}$	0.96784	735.56	14.223
1 atm	101,325	1.01325	1.0332	$\equiv$ 1 atm	760	14.696
1 torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	$\equiv$ 1 Torr; ≈ 1 mmHg	19.337×10^{-3}
1 psi	6.894×10^3	68.948×10^{-3}	70.307×10^{-3}	68.046×10^{-3}	51.715	$\equiv 1\ \mathrm{lbf/in^2}$

MEASUREMENT OF LOW PRESSURES - which are less than 1 psi, are normally considered as low pressure and low pressures are usually calibrated in inches of water. (1 psi = 27.7 inches of H20)

HEAD PRESSURE - expression head pressure, or pressure head, is often used to describe the weight of the liquid above the point at which the pressure is being described. This pressure depends only on the height of the liquid above that point and the liquid density (mass per unit volume). In terms of an equation, if a liquid is contained in a tank.

MANOMETERS

- very simple device used to measure pressure
- a fluid-filled tube where an applied gas pressure causes the fluid height to shift proportionately.
- the term **manometer** is derived from the ancient Greek words '**manós**' , meaning *thin or rare*, and '**métron**'.
- works on the principle of hydrostatic equilibrium and is used for measuring the pressure (static pressure) exerted by a still liquid or gas.
- **Hydrostatic equilibrium** states that the pressure at any point in a fluid at rest is equal, and its value is just the weight of the overlying fluid.
- a U-shaped tube consisting of an incompressible fluid like water or mercury. It is inexpensive and does not need calibration.

MANOMETER TYPES

1. **U-Tube Manometers** - It consists of a glass tube bent like the letter 'U'. In this type of manometer, balancing a column of liquid is done by another column of the same or other liquid.

2. **Well Manometers** - the well area is larger than the area of the tube, denoted by A. The rise in liquid level in the tube is considered while that in the well is ignored. If p1 and p2 are absolute pressures applied

3. **Raised Well Manometers** - similar to a well type manometer in construction. The only difference being that the vertical column limb is inclined at an angle θ.

4. **Inclined Manometers** - are used for accurate measurement of small pressure.

SPHYGMOMANOMETER

- a type of manometer, is commonly used to check blood pressure in humans.
- **Systolic pressure reading** is the mercury reading on the pressure gauge when the pulse is first heard
- **Diastolic pressure reading** is when the pulse can first no longer be heard.

DIGITAL MANOMETER

- uses a microprocessor and pressure transducer to sense slight changes in pressure. It gives the pressure readout on a digital screen. It measures differential pressure across two inputs. An analog/digital output in proportion to the instantaneous pressure can be obtained.

MECHANICAL PRESSURE ELEMENTS

MECHANICAL PRESSURE-SENSING ELEMENTS

1. **Bellows**
   resemble an accordion constructed from metal instead of fabric. Increasing pressure inside a bellows unit causes it to elongate.
   - When pressure is applied to the closed end, the bellows will be compressed. The closed end will move upwards and the link

2. **Diaphragm**
   is nothing more than a thin disk of material which bows outward under the influence of a fluid pressure
   - **Slack diaphragms**, and they are used in conjunction with external mechanisms that produce the necessary restraining force to prevent damage from applied pressure.

3. **Bourdon Tubes**
   are made of spring-like metal alloys bent into a circular shape.
   - the namesake of Eugéne Bourdon, a French watchmaker and engineer who invented the Bourdon gauge in 1849
   - The Bourdon pressure gauge operates on the principle that, when pressurized, a flattened tube tends to straighten or regain its circular form in cross-section.

ELECTRONIC PRESSURE TRANSMITTERS - devices designed to measure fluid pressure and transmit that information via electrical signals such as the 4- 20mA analog standard, or in digital form such as HART or FOUNDATION Fieldbus.

PIEZORESISTIVE SENSORS - means “pressure-sensitive resistance,” or a resistance that changes value with applied pressure.

- The **strain gauge** is a classic example of a piezoresistive element: A **Strain gauge** is a sensor whose resistance varies with applied force
- When external forces are applied to a stationary object, stress and strain are the result. Stress is defined as the object's internal resisting forces, and strain is defined as the displacement and deformation that occur

APPLICATIONS OF THE STRAIN GAUGES

1. **Measurement Of Strain -** Whenever any material is subjected to high loads, they come under strain, which can be measured easily with the strain gauges. The strain can also be used to carry out stress analysis of the member.
2. **Measurement Of Other Quantities** - The principle of change in resistance due to applied force can also be calibrated to measure a number of other quantities like force, pressure, displacement, acceleration etc since all these parameters are related to each other

DIFFERENTIAL CAPACITANCE SENSORS - Another common electrical pressure sensor

- use a change in electrical characteristics to infer pressure.
- A **capacitor** is a device that stores electrical charge. It consists of two metal plates separated by an electrical insulator.
- classic example of a pressure instrument based on the differential capacitance sensor is the **Rosemount model 1151** differential pressure transmitter

The **concentric corrugations** in the metal of the diaphragm allow it to easily flex with applied pressure, transmitting process fluid pressure through the silicone fill fluid to the taut sensing diaphragm inside the differential capacitance cell.

DIFFERENTIAL PRESSURE TRANSMITTERS - One of the most common, and most useful, pressure measuring instruments in industry

- This device senses the difference in pressure between two ports and outputs a signal representing that pressure in relation to a calibrated range.

METHODS OF PRESSURE MEASUREMENTS

1. By Means of Mechanical Pressure Sensors
2. By Means of Electrical/ Electronic/ Pressure Sensors/Elements/ Transducers

Working Principle

System or line pressure is applied to the internal volume of the bellows. As the inlet pressure to the instrument varies, the bellows will expand or contract. The moving end of the bellows is connected to a mechanical linkage assembly. As the bellows and linkage assembly moves, either an electrical signal is generated, or a direct pressure indication is provided. The bellows must always be opposed by a spring, and the deflection characteristics will be the resulting force of the spring and bellows.

The bellows are used in two forms.

1. **Pressure is applied to one side** of the bellows and the resulting deflection is counterbalanced by a spring.
2. **The differential pressure is also indicated.** One pressure is applied to the inside of one sealed bellow while the other pressure is applied to the inside of another sealed bellow.

Absolute pressure sensors

The first one is the reference bellows, which is provided with a perfect vacuum on the inside. The second one is the measuring bellows, which is subjected to the process pressure. Absolute pressure sensors are generally used to measure low pressures, the bellows are not equipped with calibrated springs, and they are used in expansion. The bellows will stretch with increasing process pressure.

Basic construction/Materials

The bellows are made up of an alloy with high strength and ductility. It should have very little hysteresis effect. Commonly brass or phosphor bronze is used for making bellows. For selecting a specific material for bellows, the parameters to be checked are: (i) Range of pressure (ii) Hysteresis (iii) Fatigue on dynamic operation (iv) Corrosion (v) Fabrication ease (vi) Sensitivity to fluctuating pressures.

The Diaphragm Pressure Sensor

uses the elastic deformation of a diaphragm (i.e., membrane) instead of a liquid level to measure the difference between an unknown pressure and a reference pressure. 20 ▫ Diaphragms are well developed and proven. Modern designs have negligible hysteresis, friction and calibration problems when used with smart instrumentation.

MATHEMATICAL EQUATION

A typical Diaphragm pressure gauge contains a capsule divided by a diaphragm, as shown in the schematic. One side of the diaphragm is open to the external targeted pressure, PExt, and the other side is connected to a known pressure, PRef,. The pressure difference, PExt – PRef, mechanically deflects the diaphragm.

BASIC CONSTRUCTION/MATERIALS

There are two main types of construction and operation of diaphragm sensors.

- **Motion Balanced** designs are used to control local, direct reading indicators. They are however more prone to hysteresis and friction errors.
- **Force Balanced** designs are used as transmitters for relaying information with a high accuracy, however they do not have direct indication on capability.

BOURDON TUBE SENSOR TYPES

1. C-TYPE
2. SPIRAL TYPE
3. HELICAL TYPE

BOURDON TUBE

The Bourdon tube is the namesake of Eugéne Bourdon, a French watchmaker and engineer who invented the Bourdon gauge in 1849

C-TYPE BOURDON TUBE SENSOR

- C-Type Bourdon Tube works on a simple principle that a bent tube will change its shape when exposed to variations of internal and external pressure. It is known for its very high range of differential pressure measurement in the range of almost 100,000 psi (700 MPa). It is an elastic type pressure transducer.

Parts and working principle.

The pressure input is given to a socket which is soldered to the tube at the base. Tip is connected to a segmental lever through an adjustable length link. The lever length may also be adjustable. ▫ A hair spring is used to fasten the spindle of the frame of the instrument to provide necessary tension for proper meshing of the gear teeth

SPIRAL TYPE BOURDON TUBE

- For low pressure ranges, the spiral is made of a flat oval tube, while a round tube is being used for the high-pressure ranges.
- The use of spiral Bourdon tubes is consequently more likely in the high-pressure ranges which cannot be measured with the C-shaped tube because the wall thickness of the tube would be too large so that the tip movement is too small to have sufficient accuracy.

APPLICATION OF SPIRAL TYPE

- It is mainly used in low- pressure applications.

PRINCIPLES OF OPERATION

- The spiral Bourdon tube makes a few windings in one plane around the fixed shaft of the pointer.
- When the tube is being uncoiled by the process pressure, the free end will have a larger displacement compared to the C-shaped tube. The more windings, the larger the displacement will be.

- A transmission mechanism is therefore no longer necessary. When the number of windings is correctly determined for a selected measuring range, a fixed connection between the free end of the Bourdon tube and the pointer is sufficient for a full deflection on the scale.
- Using a fixed link avoids transmission losses due to friction or backlash in the transmission mechanism. This increases the accuracy and sensitivity of the pressure gauge. Also, recalibration is no longer necessary.

HELICAL TYPE BOURDON TUBE

- Is a bourdon tube wound in the form of a helix. It allows the tip movement to be converted to a circular motion.

PRINCIPLES OF OPERATION

Working Principle:

- Helical is a bourdon tube wound in the form of a helix. It allows the tip movement to be converted to a circular motion.
- By installing a central shaft inside the helix along its axis and connecting it to the tip, the tip movement becomes a circular motion of the shaft.

TRANSDUCER PIEZORESISTIVE STRAIN GAUGE

Principles of Operation

- **Piezoresistive strain gauges** are among the most common types of pressure sensors. They use the change in electrical resistance of a material when stretched to measure the pressure.
- **These are suitable for a variety of applications** because of their simplicity and robustness. They can be used for absolute, gauge, relative and differential pressure measurement, in both high- and low pressure applications.
- **The basic principle of the piezoresistive strain gauge is to use a strain gauge made from a conductive material that changes its electrical resistance when it is stretched.** The strain gauge can be attached to a diaphragm that recognizes a change in resistance when the sensor element is deformed. The change in resistance is converted to an output signal

Change in Resistance of Conductor

- The resistance of a conductor is proportional to its length so stretching increases the resistance
- As the conductor is stretched, its cross-sectional area is reduced, which also increases the resistance
- The inherent resistivity of some materials increases when it is stretched

Functionality

- Piezoresistive strain gauge measurements are made using a Wheatstone bridge circuit.

Basic Construction/Materials

- One or more strain gauge sensors made from a length of wire can be attached to the surface of a diaphragm.
- Semiconducting materials, most commonly silicon, can also be used to make piezoelectric strain gauge. The characteristics of the sensing element, particularly the size of the piezoresistive effect, can be adjusted by doping; in other words, by adding carefully controlled amounts of impurities (dopants) to the semiconductor.
- More lightly doped silicon results in a higher resistivity and a higher gauge factor. However, this also increases the thermal sensitivity of both the resistance and gauge factor. Capacitive Pressure Transducer
- It is a pressure measurement device, which converts applied pressure into a current signal, like 4-20mA. Capacitive type pressure transmitter is a differential pressure type sensor.
- Capacitive pressure transmitter works under the principle of differential capacitance. Principles of Operation
- Capacitive pressure measurement involves sensing the change in capacitance that results from the movement of a diaphragm.
- A linear change in capacitance with changes in the physical position of the moving element, may be used to provide an electrical indication of the element's position. Generally, the capacitance is defined by the equation:

$C = A\varepsilon/d$
C – Capacitance between two conductors
A – Area of overlapping between those conductors
d – Distance separating the conductors
ε – Dielectric permittivity of the insulating medium

Principles of Operation

The permittivity of the medium and the area of overlapping will be constant in this case, the only varying parameter, in this case, is the distance between the conductors which varies when the pressure varies, which changes the capacitance. So, the pressure variation results in the capacitance variation.

Piezoelectric Transducers?

Piezoelectric transducers are a type of electroacoustic transducer that convert the electrical charges produced by some forms of solid materials into energy. The word "piezoelectric" literally means electricity caused by pressure.

Piezoelectric Transducer works with the principle of piezoelectric, where the faces of the material are coated with a thin layer of conducting material. When stress is applied, ions in the material move towards one of the conducting surfaces while moving away from the other, generating charge. The polarity of the produced charge depends on the direction of the applied stress.

TYPES OF PIEZOELECTRIC MATERIALS

Some of the types of piezoelectric materials are: Naturally Available Ones: Quartz, Rochelle salt, Topaz, Tourmaline-group minerals, and some organic substances such as silk, wood, enamel, bone, hair, rubber, dentin.

Artificially manufactures piezoelectric material are Polyvinylidene difluoride, PVDF or PVF2, Barium titanate, Lead titanate, Lead zirconate titanate (PZT), Potassium niobate, Lithium niobate, Lithium tantalate, and other lead-free piezoelectric ceramic.

POTENTIOMETRIC PRESSURE TRANSDUCER

Principle of Operation

- The principle of the potentiometric pressure measurement is based on the change in resistance of a potentiometer.
- The wiper of the potentiometer is mechanically connected to a pressure-sensitive element, such as a Bourdon tube, a bellows, a capsule or a diaphragm. The deflection of the pressure-sensitive element determines the position of the wiper on the potentiometer.
- As a result, the resistance value changes between the wiper and one end of the potentiometer. This resistance value is a measure of the pressure applied to the sensing element.

Basic Construction/ Materials

- It started with a Bourdon tube attached to a potentiometer, creating the first potentiometric pressure transducer.
- A few years later followed by the unbonded and bonded strain gauges.
- The change in electrical resistance that is due to pressure changes, was always the basic principle.
- A potentiometer mainly consists of a resistance element having a connection terminal at each end, a sliding track that is connected to the third terminal, a wiper, and the housing.

ACCESSORIES

PRESSURE SNUBBER

- A pressure snubber is a device used to suppress excessive pressure or rapid movement in mechanical systems.
- The pressure snubber is designed to dampen the effect of pressure pulses and spikes to ensure longer life and readability of pressure gauges in difficult applications.
- It is offered in a selection of porous, piston or regulating designs.

TYPES OF PRESSURE SNUBBER

1. **Porous disk snubber:**
    - At the low-cost end of the damping spectrum is the type of porous disk (also known as the “filter type”).
    - The fixed disc creates a semipermeable barrier between the incoming pressure and the manometer hole.
    - The pressure is with that disk and has its force distributed through the metal mesh, decreasing it so that it does not damage the meter.
    - The pressure increases gradually, so that the meter does not jump a gear or explode a bourdon tube.
2. **Piston type snubber:**
    - A piston-type damper has a slightly more advanced design that is often self-cleaning.
    - Often designed in two pieces, the piston inside the shock absorber moves freely, acting as a barrier to the rapid increase in pressure.
    - When the pressure increases too quickly, the piston is forced against the hole that leads to the manometer, stopping the flow for milliseconds.
    - The diameter of the piston and its free space inside the snubber determine the speed of “damping” that occurs.
3. **Adjustable snubber:**
    - Adjustable snubber takes that fine adjustment to another level.
    - Many use a combination of a control ball to block surges and a kind of throttle valve to soften the flow of material in the meter.
    - The control of the ball acts much like the piston-type damper, since it is a passive element until a rapid change of pressure puts it into action.

Principles Of Operation

A small orifice in an adapter fitting dampens shock and fluctuating pressure effects by limiting the rate at which flow enters. The smaller the orifice, the greater is the dampening effect

OIL-FILLED

- In a liquid-filled pressure gauge, usually the case is filled with a non-aqueous fluid that effectively dampens vibration, pulsation and pressure spikes.

TYPES OF LIQUID-FILLED GAUGES:

1. **Glycerin**. Glycerin-filled gauges are a good value and provide good vibration dampening for applications at room temperature. These gauges work well in temperatures between -4°F and +140°F (-20°C and +60°C).
2. **Silicone.** Have lower viscosities even at very low temperatures; better for applications with extreme temperature variations, especially in colder climates and when icing may be expected. Their working temperature range extends from -40°F to +140°F (-40°C to +60°C).
3. **Halocarbon.** Better suited to applications that involve oxidizing agents. such as chlorine, oxygen, and hydrogen peroxide. They work within the same

temperature range as glycerin-filled gauges, that is from -4°F to +140°F (- 20°C and +60°C).

PRESSURE GAUGE SYPHONS

- A pressure gauge syphon is a device used to protect pressure gauges against the effect of high temperature environments as well as reducing the effect of pressure surges that could potentially damage the function of a pressure gauge.

TYPES OF PRESSURE GAUGE SYPHONS

1. **Coil Siphon/Syphon**
    - used primarily for horizontal installations.
    - The coil shaped design is commonly used in the industries.
2. **Pigtail Syphons**
    - used primarily for vertical installations
    - Used to protect the pressure gauge from the effect of hot pressure media, temperature above 65°C.

III. LEVEL MEASUREMENT

LEVEL MEASUREMENT - defined as the height or vertical distance of a material from a datum or a fixed reference point. Normally, the reference point is the bottom of the tank or vessel that contains the material.

Units of Level:

1. as DISTANCE- Inches, Meters, etc
2. as % of level span (40%,90%, etc.)

How is Level Measured?

Level is measured at the position of the interface between phases, where the phases are liquid/gas, solid/gas, or immiscible liquid/liquid.

MANNERS OF LEVEL MEASUREMENT

1. **Innage** - the datum line is at the bottom of the tank, vessel, or container. The measurement is taken in the liquid from the datum line to the surface of the liquid.
2. **Outage or Ullage** - the datum line is located above the position of the surface of the liquid or solid. - the measurement is taken out of the liquid from the datum line to the surface of the liquid or solid.

METHODS OF LEVEL MEASUREMENT

1. **Direct** – simple, almost straightforward and economical; it uses a direct measurement of the distance (usually height) from the datum line, and used primarily for local indication.
2. **Indirect** - This type of method level is measured in terms of the variables which change with change in level of liquid. Such variables are hydrostatic pressure, attenuation of radioactive energy, electrical properties.

GENERAL TYPES OF LEVEL MEASUREMENT

1. **Point Level -** interest is only at a certain level or depth
2. **Continuous Level -** interest is over a range of levels or depth, typically) to100% on operating range

INDUSTRIAL LEVEL MEASUREMENT METHODS

1. Visual Methods
2. Float Method
3. Displacer Method
4. Pressure or Differential Pressure Method
5. Diaphragm Box Method
6. Bubbler Method
7. Capacitance Method
8. Conductance Method
9. Time Of Flight Method
10. Nucleonic Method

I. **VISUAL METHODS OF MEASURING LEVEL**
    a. Dipstick
    b. Lead Lines
    c. Gauge and Sight Glass

DIPSTICK - oldest form of level measuring device that is essentially a stick or rod that is calibrated to indicate level.

Working Principle

- Dipstick is lowered vertically into a tank or vessel until it reaches a reference point.
- Usually the bottom of the tank is used to ensure that the stick is inserted to the correct depth.
- The dipstick is then withdrawn and the level is read by determining where the interface made contact with the dipstick. Reading the scale on the dipstick indicates the level measurement.

ADVANTAGES	DISADVANTAGES
simple, cheap, instant	Need to remove to read
can be used by any wet material and not affected by density	

LEAD LINES - acts in the same way as a dipstick. A steel measuring

- tape with a weight attached, the lead line can be used in the most places that the dipstick can.

ADVANTAGES	DISADVANTAGES
easier to handle than dipsticks	it requires action be performed
can measure much higher levels than dipsticks	no continuous representation of process measurement

GAUGE AND SIGHT GLASSES - provides continuous measurement and can also be employed in both open and closed tank applications

Working Principle

The sight glass is a transparent tube of glass or plastic mounted outside the vessel and connected to the vessel with pipes. The liquid level in the sight glass matches the level of liquid in the process tank

TYPES OF LEVEL GAUGES

1. **Transparent Level Gauge**
    - Employ two transparent glasses fitted with a liquid chamber on either side. The liquid level is indicated as a result of difference in the transparent properties of the two media. For water / steam applications, an illuminator is mounted on the rear side of the gauge with its light rays deflected upward into the water column.
2. **Magnetic Level Gauge**
    - A float-containing magnet follows liquid level in the liquid chamber, which corresponds to the level in the tank. Position of the float inside the chamber is indicated outside by bi-colored flapper embedded with a magnet by 180 Deg rotation and setting into uniform color along the traverse of the float.
3. **Reflex Level Gauge**
    - Use glasses having the face fitted towards the chamber shaped to have prismatic grooves with a section angle of 90°. When in operation, the chamber is filled with liquid in the lower part and gasses or vapors in the upper part.

II. FLOAT METHOD

- A float is a device that follows the level variations of the liquid and transmits these variations to a pointer through cable or tape, which passes over a pulley as counter weight. The float itself must be substantially lesser density than the substance of interest, and it must not corrode or otherwise react with the substance.

FLOAT SWITCH - are inexpensive way to detect level of liquid at a specific level

III. DISPLACER METHOD

Archimedes' Principle:
A body immersed in a liquid will be buoyed up by a force equal to the weight of the liquid it displaces. This upward pressure acting on the area of the displacer creates the buoyant force. Variable displacement level devices utilize this principle by measuring the weight of the immersed displacer.

Basic principle:
A displacer must be connected to a measuring mechanism which, when sensing the changes in buoyant force, converts this force into an indication of level. A displacer body can be suspended directly in a tank, or installed in a float chamber outside of the vessel.

IV. CONDUCTIVITY METHOD

Principles of Operation:
Two electrodes are positioned in a tank. One extends to the minimum level; the other is positioned so that its lower edge is at the maximum level. The tank is grounded and functions as the common, or third electrode. Usually, a stilling well is provided to ensure that the interface is not disturbed and to prevent false measurement.

CONDUCTANCE AND RESISTANCE TYPE

- The terminals of the electrodes are connected to relays, which transmit signals to a display or control device. If the process level contacts any portion of the electrode that extends to the minimum level, a conductive path is established through the grounded tank to the electrode.
- If the level falls below this electrode, the path is interrupted given that the gas or vapor is nonconductive.
- The level condition may then activate a device , which sounds an alarm or energizes a control device to operate a pump, feed controller or other processing equipment.

ADVANTAGES	DISADVANTAGES
There are no moving parts	They are invasive (meaning they must touch the product being sensed)
They are low cost	They only sense conductive liquids
Fairly easy to use	The probe will erode over time

V. CAPACITANCE METHOD

Principles of Operation:
The principle of operation of capacitance level indicator is based upon the familiar capacitance equation of a parallel plate capacitor given by:

$$C = K (A/D)$$

C = Capacitance in farad
K = Dielectric constant
A = Area of plate in m2
D – Distance between two plates, in m

Capacitance of a capacitor is directly proportional to the dielectric constant, and this principle is utilized in the capacitance level indicator. As material contacts the probe, the radio frequency shifts indicating an increase in capacitance C. **Application:** Liquids

ADVANTAGES	LIMITATIONS
The primary sensing element is very simple and rugged and has no moving parts.	Viscous conducting liquids, which coat the sensing element can cause erroneous or false readings unless a detector which compensates for coating is used.
They can be used to measure levels of liquids and powdery	

or granular materials.	
Capability for temperature, pressure and corrosion resistance is easily obtained.	
The sensing elements are easily cleaned, and sanitary standards are readily met.	

CAPACITANCE LEVEL MEASUREMENTS

1. Rotating Paddle Switch
2. Vibration Fork

Rotating Paddle Switch

- used to detect the presence and absence of solids in a process tank.
- The device makes use of a motor which slowly rotates a paddle in the absence of material, and rotates itself to actuate a switch when the paddle is prevented from turning by the presence of material.
- They may be used for both high and low level point control.
- Typical application- Lime silos

Rotating paddle:

- Industry: Water and wastewater
- Application: Lime silo measurement, Hi and re order levels.

Vibration Fork

Principle:

Tuning Fork Sensors are point level switches that are designed to detect low or high levels of liquids. It is based on the vibrating tuning fork principle, using piezoelectric crystals. The switch vibrates at a resonant frequency. When the tuning fork is submerged in the product, the frequency changes. This change is detected by the integrated oscillator and converted into a switching output.

VIBRATING FORK SENSORS

- This type of control features a tuning fork as a sensing probe.
- A piezoelectric crystal vibrates the probe when there is no material surrounding it. When material contacts the probe, the circuitry detects its presence and operates a contact closure.
- The natural frequency of oscillation is approx. 1300 Hz and 1400 hz.
- Vibratory controls can be used for both high and low level detection.

VI. DIFFERENTIAL PRESSURE METHOD

Level measurement using hydrostatic principle with differential pressure transmitter. Application: almost in all applications, especially between gaseous and liquid interfaces such in boilers.

The Pressure of liquid in an open tank depends on two factors:

- The elevation of the liquid above the measurement point
- The specific gravity (relative density) of liquid – Pressure head = PH= height x specific gravity (expressed as head water)

VII. DIAPHRAGM BOX

Principles of Operation:

Another open tank level measuring instrument which uses the hydrostatic head principle is the diaphragm box.

The diaphragm box is submerged in the process liquid and connected to a pressure gauge by gage line. The hydrostatic head produced by the level of the liquid in the tank exerts pressure on the bottom of the diaphragm causing it to flex upward.

This action compresses the gas in the box and the gauge line.

The pressure is applied to a gauge or other pressure element that is part of an indicator assembly calibrated to indicate liquid level units.

As the level in the vessel rises, the pressure exerted by the hydrostatic head on the diaphragm increases in direct proportion. The diaphragm will continue to flex until the pressure of the gas in the box and the gage line is equal to the pressure exerted by the level of the liquid on the bottom of the diaphragm.

DISADVANTAGES
The diaphragm is in contact with the process liquid. This may preclude its use in corrosive process applications.
A diaphragm can admit gas into a process liquid. In some instances, this can be detrimental to the process.
The system is also sensitive to changes in volume and pressure caused by changes in temperature.

VIII. BUBBLER METHOD

The simple level measurement has a dip tube installed with the open end close to the bottom of the process vessel. A flow of gas, usually air or nitrogen passes through the tube and resultant air pressure in the tube corresponds to the hydraulic head of the liquid in the vessel. The air pressure in the bubbler tube varies proportionally with the change in head pressure.

Application: Liquids

BUBBLER TUBE PURGE OF LEVEL MEASUREMENT

- One method of monitoring/controlling liquid level in a tank is the use of Bubbler Tubes with Pressure or Differential Pressure Transmitters. A small but uninterrupted flow of air or inert gas is forced down through a dip tube which extends to near the bottom of the tank.
- The pressure transmitter takes the back pressure and converts it to an analog signal that is sent to the control

room. The plant operator will then be able to monitor the exact level in the tank.

ADVANTAGES	DISADVANTAGES
Simplicity of design	It is frequently necessary to periodically clean this device
Low initial purchase	The tip of the pipe can collect material from the process, solidify and plug the hole
It can be mounted at any location and elevation with respect to the tank.	Bubblers are not suitable for use in non vented vessels.
Most useful applications such as underground tanks and water wells.	They are generally limited to open-tank applications.

IX. TIME OF FLIGHT METHOD

1. Ultrasonic Level Measurement
2. Radar Level Measurement

ULTRASONIC LEVEL MEASUREMENTS

Principle:

Ultrasonic devices operate on the echo principle. When sound waves contact solid or liquid surfaces , only a small proportion of the sound energy in the wave penetrates the surface. Most of the sound is reflected. The reflected sound wave is an echo. A sound wave is usually generated at a frequency of about 20kHz.

Application: Liquids and Slurries

Continuous ultrasonic level measurement systems are designed to measure the time of flight of a reflected sound wave. In other words, it measures the time required for an ultrasonic sound wave to travel to the process surface and be reflected back to the receiver. The generic name for such a device is sonar.

Note: Technology is limited by the shapes of surfaces and the consistency of the material. For example foam on the surface of a liquid in a tank could distort a reading.

ADVANTAGES	DISADVANTAGES
Essentially no moving parts	More expensive and sophisticated than the more conventional measuring systems.
Accuracy is good where application is suitable	
Application to some difficult-to-measure streams such as powders, solids, solid-contacting fluids and slurries	Ultrasonic techniques are generally reserved for those applications in which the use of conventional systems would present serious difficulties and yield less successful results
Easy to install	
Capability for continuous measurement without contacting the process material	

RADAR LEVEL MEASUREMENTS

Radar method

- radar instruments operate by transmitting a high frequency (GHz) electromagnetic radiation and timing the transit time to the level surface and back.
- Uses time of flight Technology of radar and microwave signals which is used for Level measurements.

Principle:

The two technologies on the market are:

1. **Frequency Modulated Continuous Wave(FMCW)**
   - Continuously emit a swept frequency signal and distance is inferred from the difference in frequency between the transmit and receive signals at any point in time. FMCW is therefore the only method that is suitable for the high accuracy demanded for tank gauging
2. **Pulsed Wave Time of Flight (PWTF)**
   - Emit a microwave burst towards the process material , this burst is reflected by the surface of the material and detected by the same sensor which now acts as a receiver. Level is inferred from the time of flight (transmission to reception) of the microwave signal. Microwave "echoes" are evaluated by sampling and building up a historical profile of the echoes.

Radar Type (Non contact)

- Radar level instruments send radio waves out through open space to reflect off the process material. The instruments relying on open space for signal propagation are called non contact radar.

Radar type Guided-wave Radar (GWR)

- Radar level instruments use waveguide "probes' ' to guide the radio waves into the process liquid. The instruments using wave guided-wave are called guided wave radar instruments

Radar Gauge Applications:

Radar gauge effectively overcome the difficulties of level measurement problems such as:

- Agitations
- Density change
- Temperature change
- Vapors
- Condensates
- Changing dielectric when selecting a level measurement technology, consider the reliability, accuracy, and versatility of radar technology

X. NUCLEONIC METHOD

NUCLEAR LEVEL MEASUREMENT

One of the most effective methods of shielding against gamma ray radiation is with very dense substances such as lead or concrete. That is why the source boxes holding gamma-emitting radioactive pellets are lined with lead, so the radiation escapes only in the direction intended. These "sources" may be locked out for testing and maintenance by moving a lever that hinges a lead shutter over the window of the box. This lead shutter acts as an on/off switch for the radioactive source.

The lever actuating the shutter typically has provisions for lock-out/tag-out so the maintenance person may place a padlock on the lever and prevent anyone else from “turning on” the source during maintenance.

Nuclear continuous level measurement works by directing a narrow fan of radiation through the vessel to a detector. As the process level rises, it shields the detector from the radiation.

The more radiation the detector “sees” the lower the process level (discernable to 1% of span). The less radiation detected, the higher the process level.

Applications: Used in many difficult applications such as High Temperature, High Pressure, Toxic and sticky material

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IV. FLOW RATE MEASUREMENT

FLOW RATE

- “Flowrate " or simply “flow” is defined as the volume or mass quantity of fluid that flow rates through the section of a pipe or channel per time unit. It may refer to volumetric flow rate (the number of fluid volumes passing by per unit time), mass flow rate (the number of fluid mass units passing by per unit time), or even standardized volumetric flow rate (the number of gas volumes flowrating, supposing different pressure and temperature values than what the actual process line operates at)

The major factors affecting the flow rate of fluids through pipes are:

- the velocity of the fluid.
- the friction of the fluid in contact with the pipe.
- the viscosity of the fluid.
- the density of the fluid

- **Fluid velocity depends on the head pressure which is forcing the fluid through the pipe.**

  The greater the head pressure, the faster the fluid flow rate (all other factors remaining constant), and consequently, the greater the volume of flow rate. Pipe size also affects the flow rate. For example, doubling the diameter of a pipe increases the potential flow rate by a factor of four times.
- **Pipe friction reduces the flowrate rate of fluids through pipes and is, therefore, considered a negative factor.** Because of the friction of a fluid in contact with a pipe, the flowrate of the fluid is slower near the walls of the pipe than at the center. **The smoother, cleaner, and larger a pipe is, the less effect pipe friction has on the overall fluid flow rate**
- **Viscosity,** or the molecular friction within a fluid, negatively affects the flow rate of fluids. Viscosity and pipe friction decrease the flowrate of a fluid near the walls of a pipe. **Viscosity increases or decreases with changing temperature, but not always as might be expected.**
- **Density** of a fluid affects flow rate rates in that a more dense fluid requires more head pressure to maintain a desired flow rate rate. Also, the fact that gasses are compressible, whereas liquids essentially are not, often requires that different methods be used for measuring the flowrate rates of liquids, gasses, or liquids with gasses in them. It has been found that the most important flow rate factors can be correlated together into a dimensionless parameter called the **Reynolds Number.**

PHYSICAL NATURE OF FLOW RATE

Laminar and Turbulent Fluid Flow Rate (Reynolds number)

Laminar refers to an orderly motion of flowrate where every particle of the fluid moves in parallel to the pipe. However, the fluid flowing close to the wall slows down due to friction and viscosity. The flowrate is said to become turbulent when it speeds up even more. The two types can be demonstrated easily by injecting a small jet of colored water slowly into a clear liquid stream in a transparent pipe. At low flow rate, the colored water shows an even and with little diffusion in the surrounding stream. When a similar jet is released in a high velocity stream, the diffusion is almost immediate and uniform across the section.

The Reynolds number (Re) tells us if the flowrate is Laminar or turbulent;

- If less than 2000, it is laminar
- If more than 4000, it is turbulent

Importance of Flow Rate Measurement

Measurement of flow rate, whether it is a liquid or gas, is commonly a critical parameter in many processes. **In most operations it is important to know that the right fluid is at the right place at the right time.** Some critical applications require the ability to conduct accurate flow rate measurements to ensure product quality.

Health & Safety is always an important factor when working with liquids and gasses, investment in ensuring your team can operate in a safe and productive environment is very important. Measuring flowrate and pressure can provide this security to the process and personnel.

Fluid flow rate metering systems provide vital information for the following purpose :

1. **Production Planning -** the quantities of product supplied to customers generally vary according to seasonal demand. Usually an average rate of production is planned on a calendar day which takes into account any periods of shutdown necessary for maintenance and inspection.
2. **Product Quality** - flow rate controllers are necessary in the proportional blending of intermediate products to produce on-specification finished products of consistent quality.
3. **Control of Process -** sometimes flow rate meters are used for control of some other main process variables.

A. Pressure-based flow rate meters

Differential pressure flow rate instruments create a differential pressure in a fluid flowing through a pipe which can be measured and presented in terms of rate of flow. A restriction is placed in line of a flowing fluid producing a differential pressure across the restriction element, and the flowrate is proportional to the square root of the differential pressure.

Bernoulli Equation finds its major use in this type of flow rate measurement.

TYPES OF FLOW RATE METERS THAT EMPLOY THIS PRINCIPLE ARE

1. Orifice Plates
2. Venturi
3. Pitot tubes,
4. Flow Rate Nozzle.

ORIFICE PLATES

- simply a disc with a hole
- Orifice plate functions as the primary element; it creates restriction as well as differential pressure between the upstream and downstream sides. The pressure on the upstream is higher than the pressure at the downstream, and this pressure difference is directly proportional to the velocity and rate of flowrate of the fluid.

Types of Orifice Plates

1. Square-edge Orifice Plate
    - Concentric Orifice Plate
    - Eccentric Orifice Plate
    - Segmental Orifice Plate
2. Non-square-edge Orifice Plate
    - Quadrant-edge Orifice Plate
    - Conical-entrance Orifice Plate

VENTURI TUBE

- is a pipe purposefully narrowed to create a region of low pressure.
- The greater the height of the liquid column in the piezometer, the greater the pressure at that point in the flowrate stream: **The classic venturi tube pioneered by Clemens Herschel in 1887 has been adapted in a variety of forms broadly classified as flowrate tubes.**

Variations of Venturi Tube

1. **Flow Rate nozzle -** is designed to be clamped between the faces of two pipe flanges in a manner similar to an orifice plate. The goal here is to achieve simplicity of installation approximating that of an orifice plate while improving performance (less permanent pressure loss) over orifice plates.
2. **V-cone** may be thought of as a venturi tube or orifice plate in reverse:instead of narrowing the tube's diameter to cause fluid acceleration, fluid must flow rate around a cone-shaped obstruction placed in the middle of the tube. The tube's effective area will be reduced by the presence of this cone, causing fluid to accelerate through the restriction just as it would through the throat of a classic venturi tube.
3. **Segmental wedge** elements are special pipe sections with wedge-shaped restrictions built in. These devices, albeit crude, are useful for measuring the flowrate rates of slurries, especially when pressure is sensed by the transmitter through remote-seal diaphragms (to eliminate the possibility of impulse tube plugging

PITOT TUBES

- The Pitot tube senses pressure as the fluid stagnates (comes to a complete stop) against the open end of a forward-facing tube. The principle of Pitot tube is a variable head velocity measuring device. It consists of two concentric tubes bent at right angles. Inner tube faces the impingement and hence measures the static and dynamic pressures while the outer tube measures the static pressure. The tube lies along the flowrate axis having an open end facing into the flowrate is called the impact probe/tip. The second tube resides around the pipe wall and it has a hole tangential to the flowrate called the static probe.

B. Turbine Meters

It is very commonly used for measuring condensate, crude oil and diesel.

The flowrate of the liquid causes the rotor to spin at an angular velocity which is proportional to the velocity of the liquid. The speed of the rotor is detected by a pickup on the outside of the tube, usually by an electromagnetic detector to provide a pulsed electrical signal proportional to flow rate pressure head drop across the turbine. There are some mechanical friction effects, but these are negligible except at low flow rates. They are generally used for liquid flow rate only. These meters are delicate and do not like sudden high flow rates caused by gas pockets, or valves sudden opening

C. Positive Displacement Meter

This form of flow rate meter divides up the flowing fluid into known volume packets. These measurement devices trap a known volume of fluid and allow it to pass from meter inlet to outlet. The number of trapped volumes passing through the meter is counted to obtain the total flow rate. These are then counted to give the true value of the volume passing through. If the volume delivered over a particular time is monitored, the volume flowrate rate is established. **The term displacement means that the fluid that flows through the meter replaces (displaces) the volume of fluid that flowed through the meter immediately before.**

D. Magnetic flow rate meter

This type of flow rate meter uses the principle of inductive voltage/current in accordance with Faraday's Law and Lenz's Law. Two metal electrodes fit into the wall of the tubing flush with the inner wall at opposite sides of the pipe. Two specially shaped magnetic coils are then attached to the pipe to produce a uniform magnetic field at the right angles to the pipe. The meter works by using the flowing liquid as a conductor, moving across the meter generated magnetic field

A voltage is induced across the moving liquid and the amplitude of this voltage is proportional to the velocity of the liquid and the strength of the magnetic field. This induced voltage is fed to the measuring amplifier by the electrode pair. The magnetic flow rate meter has no moving parts and offers no restriction to the flow rate, nor any pressure drop running through it. Its accuracy does not depend on viscosity since it measures by volume. So it can be used for highly viscous slurries or liquids with varying viscosities

E. Ultra-Sonic Flow Rate meter

The term ‘ultra sonic’ is used to describe pressure waves at frequencies higher than the human ears can detect. The velocity of the sound waves in the fluid is the same as the velocity of sound in the fluid. If an ultrasonic beam is transmitted across a pipeline at an angle to the flowrate direction, the time taken for the pulse to reach the receiver is a function of the flow rate velocity of the fluid, as well as the velocity of sound in the fluid.

Principle of Operation

Thus, this type of flow rate meter operates on the **principle of transit time differences.** An acoustic signal (ultrasonic) is transmitted from one sensor to another. This can be either in the direction of flow rate (downstream) or against the direction of flow rate (upstream). The time (transit) that the signal requires to arrive at the receiver is then measured. According to physical principles, the signal sent against the direction of flow rate requires longer to return than the signal in the direction of flow rate. The difference in the transit time is directly proportional to the velocity of flow rate

F. Vortex Flow Rate meter

Vortex flow rate meters operate on the physical principle of the **Karman vortex street.** When a fluid flows past a bluff body, vortices are alternately formed on the sides of that body and then detached or shed by the flowrate. The frequency of vortex shedding is proportional to the mean flow rate velocity and, therefore, the flowrate (with Re >4000). Alternating pressure changes caused by the are transmitted via lateral ports into the bluff body. The DSC sensor is located within the bluff body and is well protected from water hammer and temperature or pressure shocks. The sensor detects the pressure pulses and converts these into electrical signals.

G. Coriolis-Effect Meter

It is so called because the instrument employs the Coriolis Principle which states that: “A body of mass M, moving with constant linear velocity, and subject to an angular velocity, (or vibrating) experiences an inertial force at right angles to the direction of motion”. During operation, a drive coil, located at the center of the bend in the tube, is energized periodically, and causes the sensor tube to oscillate (move up and down) about the support axis as shown in the figure. The tube vibrates rapidly at a rate of 40-200 cycles per second, and through a distance of just a few hundredths of a centimeter.

H. Rotameter (Variable Area Flow Rate Meter)

Rotameters are a common type of variable area flow rate meter. Besides being a standalone meter, they can also be found on the level bubbler , and on the caissons. The rotameter consists of a tapered glass metering tube that has a float inside that is free to move up and down. A scale is engraved on the outside the tube in flow rate units. As the flow rate varies the float rises and falls and the flowrate value can be read off against the glass. The flowrate has to pass through the gap between the float and the walls of the tube, so there is a pressure drop.

V. ANALYTICAL MEASUREMENT

CONDUCTIVITY MEASUREMENT

CONDUCTIVITY

is a measure of how well a solution conducts electricity. To carry a current a solution must contain charged particles, or ions. Most conductivity measurements are made in aqueous solutions, and the ions responsible for the conductivity come from electrolytes dissolved in the water. Salts (like sodium chloride and magnesium sulfate), acids (like hydrochloric acid and acetic acid), and bases (like sodium hydroxide and ammonia) are all electrolytes. Although water itself is not an electrolyte, it does have a very small conductivity, implying that at least some ions are present. **Conductivity is not specific. It measures the total concentration of ions in solution.** It cannot distinguish one electrolyte or ion from another

APPLICATIONS OF CONDUCTIVITY MEASUREMENT

1. **Water treatment.** Raw water as it comes from a lake, river, or the tap is rarely suitable for industrial use. The water contains contaminants, largely ionic, that if not removed will cause scaling and corrosion in plant equipment, particularly in heat exchangers, cooling towers, and boilers. There are many ways to treat water, and different treatments have different goals. Often the goal is demineralization, which is the removal of all or nearly all of the contaminants
2. **Leak detection.** Water used for cooling in heat exchangers and surface condensers usually contains large amounts of dissolved ionic solids. Leakage of the cooling water into the process liquid can result in potentially harmful contamination. Measuring conductivity in the outlet of a heat exchanger or in the condenser hot well is an easy way of detecting leaks.
3. **Cleaning-in-place.** In the pharmaceutical and food and beverage industries, piping and vessels are periodically cleaned and sanitized in a procedure called clean-in-place (CIP). Conductivity is used to monitor

both the concentration of the CIP solution, typically sodium hydroxide, and the completeness of the rinse.

4. **Interface detection.** If two liquids have appreciably different conductivity, a conductivity sensor can detect the interface between them. Interface detection is important in a variety of industries including chemical processing and food and beverage manufacturing.
5. **Desalination.** Drinking water desalination plants, both thermal (evaporative) and membrane (reverse osmosis), make extensive use of conductivity to monitor how completely dissolved ionic solids are being removed from the brackish raw water.

TWO TYPES OF CONDUCTIVITY MEASUREMENT:

- **contacting** and **inductive.** The choice of which to use depends on the amount of conductivity, the corrosiveness of the liquid, and the amount of suspended solids. *Generally, the inductive method is better when the conductivity is high, the liquid is corrosive, or suspended solids are present.*

1. **Contacting Conductivity Meter**

- Most contacting conductivity sensors consist of two metal electrodes, usually stainless steel or titanium, in contact with the electrolyte solution, see Figure 3. The analyzer applies an alternating voltage to the electrodes. The electric field causes the ions to move back and forth producing a current. Because the charge carriers are ions, the current is called an ionic current. The analyzer measures the current and uses Ohm's law to calculate the resistance of the solution (resistance = voltage/current). The conductance of the solution is the reciprocal of the resistance

2. **Inductive Conductivity Meter**

- *Inductive conductivity is sometimes called toroidal or electrodeless conductivity.*
- An inductive sensor consists of two wire-wound metal toroids encased in a corrosion-resistant plastic body. One toroid is the drive coil, the other is the receive coil. The sensor is immersed in the conductive liquid. The analyzer applies an alternating voltage to the drive coil, which induces a voltage in the liquid surrounding the coil. The voltage causes an ionic current to flow proportional to the conductance of the liquid. The ionic current induces an electric current in the receive coil, which the analyzer measures. **The induced current is directly proportional to the conductance of the solution**

pH Measurement

What is pH?

- The pH unit measures the degree of acidity or basicity of a solution. **To be more exact, pH is the measurement of the hydrogen ion concentration, [H+].** Every aqueous solution can be measured to determine its pH value. This value ranges from 0 to 14 pH. Values below 7 pH exhibit acidic properties. **Values above 7 pH exhibit basic (also known as caustic or alkaline) properties. Since 7 pH is the center of the measurement scale, it is neither acidic nor basic, it is called "neutral."**
- pH is defined as the negative logarithm of the hydrogen ion concentration. This definition of pH was introduced in 1909 by the Danish biochemist, Soren Peter Lauritz Sorensen. It is expressed mathematically as:

$$pH = -log\left[H^{+}\right]$$

- where: [H+] is hydrogen ion concentration in mol/L. The pH value is an expression of the ratio of [H+] to [OH-] (hydroxide ion concentration). Hence, if the [H+] is greater than [OH-], the solution is acidic. Conversely, if the [OH-] is greater than the [H+], the solution is basic. At 7pH, the ratio of [H+] to [OH-] is equal and, therefore, the solution is neutral. As shown in the equation below, pH is a logarithmic function. A change of one pH unit represents 10-fold change in concentration of hydrogen ion

How Is pH Measured?

- pH in an aqueous solution can be measured in a variety of ways. The most common way uses a pH-sensitive glass electrode, a reference electrode and a pH meter. Alternative methods for determining the pH of a solution are:

- **Indicators**: Indicators are materials that are specifically designed to change color when exposed to different pH values. The color of a wetted sample paper is matched to a color on a color chart to infer a pH value. pH paper is available for narrow pH ranges (for example, 3.0 to 5.5 pH, 4.5 to 7.5 pH and 6.0 to 8.0 pH), and fairly wide pH ranges of 1.0to11.0pH.

- **Colorimeter:** This device uses a vial filled with an appropriate volume of sample to which a reagent is added. As the reagent is added, a color change takes place. The color of this solution is then compared to a color wheel or spectral standard to interpolate the pH value. The colorimeter can be used for grab sample measuring, but not for continuous on-line measuring. Typically used to determine the pH value of water in swimming pools, spas, cooling towers, and boilers, as well as lake and river waters.

Colorimetric pH measurement

- One of the simplest ways to measure the pH of a solution is by color. Certain specific chemicals dissolved in an aqueous solution will change color if the pH value of that solution falls within a certain range. Litmus paper is a common laboratory application of this principle, where a color changing chemical substance infused on a paper strip changes color when dipped in the solution. Comparing the final color of the litmus paper to a reference chart yields an approximate pH value for the solution

Potentiometric pH measurement

- Color-change is a common pH test method used for manual laboratory analyses, but it is not well suited to continuous process measurement. By far the most common pH measurement method in use is electrochemical: special pH sensitive electrodes inserted into an aqueous solution will generate a voltage dependent upon the pH value of that solution. Like all other potentiometric (voltage-based) analytical measurements, electrochemical pH measurement is based on the Nernst equation, which describes the electrical potential generated by a difference in ionic concentration between two different solutions separated by an ion-permeable membrane